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Development of an electrochemical sensor to determine amoxicillin in natural water based on CORE-SHELL/PVP

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ABSTRACT

In 2020, the world was affected by a new virus, SARS-CoV-2, which causes the disease known as COVID-19. Given the damage caused by the pandemic, there was a significant increase in the use of antibiotics. However, this increase causes harmful effects due to disposal in sewage systems by human and animal excretion and their manufacturing process. These drugs reach water resources, causing environmental impacts and damage. Given this current and worrying scenario, the focus of this work was to develop an alternative and lower-cost method for the detection of amoxicillin in natural urban waters, using an electrochemical sensor based on a core-shell formed by Fe_3O_4@Ag coated with the polymer polyvinylpyrrolidone. The device presented a wide linear range between 136 and 8210 µmol L^{-1} of amoxicillin, with a detection limit of 7.8 µmol L^{-1}. When applied to detect the analyte in urban natural water samples and in commercial drugs, it presented a low relative error of 2.7% and 5.1%, respectively. Thus, the device proved to be an excellent alternative for detecting antibiotics in real samples, in addition to being miniaturized, allowing low-cost field analysis.

Keywords: amoxicillin, emerging pollutant, Fe_3O_4@Ag core-shell.

Desenvolvimento de um sensor eletroquímico para a determinação de antibióticos em águas naturais baseado em CORE-SHELL/PVP

RESUMO

Em 2020, o mundo foi afetado por um novo vírus, o SARS-CoV-2, causador da doença conhecida como COVID-19. Diante dos danos causados pela pandemia, houve um aumento significativo no consumo de antibióticos. No entanto, esse aumento causa efeitos nocivos devido ao descarte em sistemas de esgoto por excreção, humana e animal, e seu processo de fabricação. Esses medicamentos atingem os recursos hídricos, causando impactos e danos ambientais. Diante desse cenário atual e preocupante, o foco deste trabalho foi desenvolver um método alternativo e de menor custo para detecção de amoxicilina em águas urbanas naturais, utilizando um sensor eletroquímico baseado em core-shell formado por Fe_3O_4@Ag revestido com o polímero polivinilpirrolidona. O dispositivo apresentou uma ampla faixa linear entre 136 e 8210 µmol L^{-1} de amoxicilina, com limite de detecção de 7,8 µmol L^{-1}. Quando aplicado para detectar o analito em amostras de águas naturais urbanas e em medicamentos comerciais, apresentou baixo erro relativo de 2,7% e 5,1%, respectivamente. Dessa forma, o dispositivo se mostrou uma excelente alternativa para detecção de antibióticos em amostras reais, além de ser miniaturizado, permitindo análises de campo de baixo custo.

Palavras-chave: amoxicilina, core-shell de Fe_3O_4@Ag, poluentes emergentes.

1. INTRODUCTION

The world has recently experienced the tragic and historic COVID-19 pandemic, a disease caused by the SARS-COV-2 virus, popularly known as coronavirus. In March 2020, after several cases and worldwide alerts, COVID-19 was characterized by the World Health Organization (WHO) as a pandemic (Buss *et al.*, 2020).

One of the consequences caused by the pandemic was the significant increase in the use of antibiotics, used to prevent and treat infections in humans and animals. A study conducted by Rabbi *et al.* (2023), indicated that in 2020 there was a 26% increase in the consumption of these drugs compared to previous years. It is estimated that the rate of bacterial co-infection during the pandemic was below 10%, but antibiotics were prescribed to 75% of patients who were infected by the virus, since there were no medications for specific treatment of the disease at that time (Nandi *et al.*, 2023).

The impacts of the antibiotics' excessive use raise several questions related to public health and environmental issues. In terms of health, the greatest concern is the increase in antibiotic resistance genes, which can promote changes in the microbial community and generate superbugs (Hossein and Ripanda, 2025). In terms of environmental impacts, the concern is related to the disposal of these compounds in hospital and domestic sewage. According to specific studies, only 15% of antimicrobial products are metabolized by the human body. The remainder can be excreted as active chemical substances (Zhao *et al.*, 2023).

Among the antibiotics prescribed, amoxicillin ($C_{16}H_{19}N_3O_5S$) has a prominent role because it is easily accessible, with broad bactericidal spectrum and has a proven high rate of efficacy, capable of covering wide range of infections in both humans and animals, due to extremely strong bactericidal effect (Chávez *et al.*, 2024; Feroze *et al.*, 2023; Wang and Zhang, 2022). In this way, amoxicillin (pKa_1 of 2.8 and pKa_2 of 7.2) is currently considered an emerging pollutant, a compound that can pose risks to the ecosystem and public health causing allergic reactions and liver and kidney dysfunction, but it is not yet regulated. Therefore, there is not enough monitoring data to measure the environmental impact caused (Cartaxo *et al.*, 2020; Li *et al.*, 2020).

Given this real and worrying scenario, it is necessary to develop alternatives for controlling, identifying and detecting these compounds in environmental matrices. Currently, the most widely used methods for determining antibiotics in natural waters are chromatographic methods, such as high-performance liquid chromatography (HPLC) (Hu *et al.*, 2024; Dousa and Hosmanová, 2005) and UPLC (Abdallah *et al.*, 2019). However, it is known that it has high operational costs and requires specific technical training. In this context, the use of electrochemical sensors is relevant, which have been widely applied for chemical pollutants. These devices allow rapid, low-cost, sensitive and highly reliable analyses in complex samples. Oliveira *et al.* (2022) as well as Souza *et al.* (2023) developed an electrochemical sensor based on printed carbon electrodes and titanium dioxide/cobalt composite to determine amoxicillin, presenting a linear region of 20 to 150 µmol L^{-1} and a limit of detection of 5.8 µmol L^{-1}. In another study, the electrochemical device was constructed using a printed cellulose nanofiber electrode modified with multi-walled carbon nanotubes wrapped in polybenzimidazole, achieving a limit of detection of 0.3 µmol L^{-1} and a wide linear range of 0.3 to 500 µmol L^{-1} (Sari *et al.*, 2023).

Great attention has been given to core-shell nanomaterials, which are composed of nanoparticles denominated as core covered with another nanoparticle as shell (Zibadi *et al.*, 2024). Core-shell structures formed by Fe_3O_4 nanoparticles have shown characteristics interesting considering electrochemical sensor development such as excellent conductivity, affordable cost and magnetic properties that facilitate the washing steps, since they are easily attracted by a magnetic field and redispersed in its absence (Li and Wang, 2024). To improve the stability of this nanomaterial, they can be coated with nanoparticles of noble metals, such as silver. Silver nanoparticles still have low electrical resistance, good conductivity and excellent biocompatibility (Palsaniya *et al.*, 2023).

To avoid the common core-shell agglutination, its coating with polymer is an efficient alternative. Polyvinylpyrrolidone (PVP) is a water-soluble polymer formed by multiple chains of vinyl pyrrolidones and it contains lactam ring as repeating unit in chain, which gives advantageous characteristics such as the ability to form stable complexes (Sophia and Muralidharan, 2015). PVP presents biocompatibility and non-toxicity and the use of PVP in sensors can also improve the mechanical and electrical properties of the devices (Pourmadadi *et al.*, 2023).

In this context, the aim of this work is to develop an electrochemical sensor based on a Fe_3O_4@Ag core-shell modified with PVP for the determination of the antibiotic amoxicillin in natural urban waters.

2. MATERIAL AND METHODS

Ammonia, $FeCl_2$, $FeCl_3$, $AgNO_3$ and PVP (PA) was obtained from Synth (Brazil). Amoxicillin (PA) and other reagents (analytical grade) were purchased from was obtained Sigma-Aldrich. Phosphate buffer solutions were obtained by mixing solutions of 0.1 mol L^{-1} Na_2HPO_4 and 0.1 mol L^{-1} NaH_2PO_4 in ultrapure water. All solutions were prepared with deionized water (> 18 MΩ cm, Milli-Q, Millipore).

2.1. Fe_3O_4@Ag Core-shell preparation

The core-shell synthesis followed the procedure adapted from Ahrberg *et al.* (2020). For the preparation, a flow-through system (FIA) was used, which allows the continuous addition of aqueous solutions of the reagents. For this purpose, a multichannel peristaltic pump was used to inject in a flow at a rate of 1.0 mL $minute^{-1}$, 4 mol L^{-1} ammonia solution (channel 1), mineral oil (Nujol) with surfactant additive Triton–X 100 0.075% and Tween-80 1.75% (channel 2) and in the third channel a mixture of $FeCl_2$ solution 0.03 mol L^{-1} and $FeCl_3$. 0.06 mol L^{-1}, as shown in Figure 1. The solution was mixed in a tap with input from 3 channels and output to the thermostatic bath at a temperature of 70°C, where the solution circulated for 10 minutes. Then, 0.03 mol L^{-1} silver nitrate was added to channel 4 and the system began to produce the core-shell continuously.

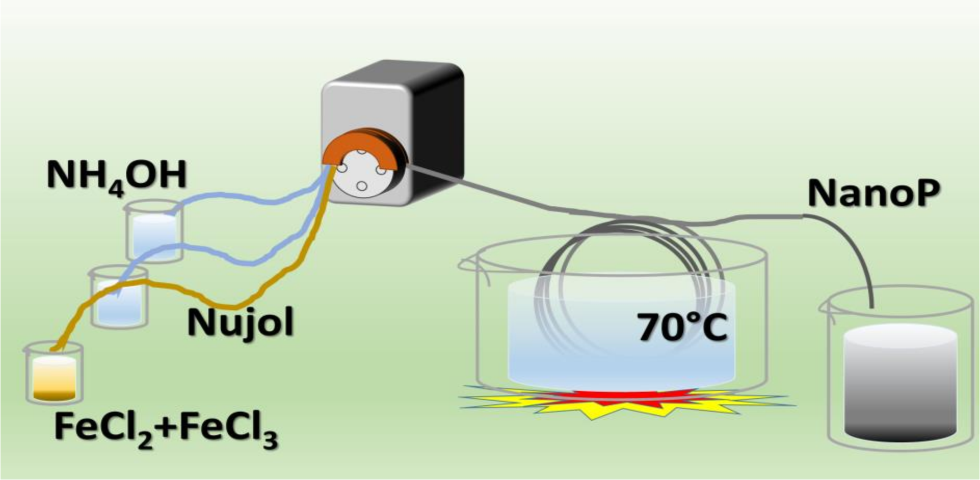

Figure 1. Schematic of the assembly for the synthesis of Fe_3O_4@Ag core-shell in a flux system.

2.2. Sensor Construction

To recover the nanostructure with the polymer, 50 µL of the core-shell solution and 50 µL of the 100 mg L^{-1} PVP solution were added to an Eppendorf ® flask and left to interact for 60 min. Afterwards, the system was washed with 0.1 mol L^{-1} phosphate buffer solution to remove the weakly adsorbed polymer. So, 5 µL of the core-shell/PVP was dripped on a graphite screen-printed electrode from Metrohm®, with dimensions of 3.4 x 1.0 x 0.05 cm. After drying the drop, it was used as a sensor for amoxicillin.

2.3. Electrochemical Measurements

The measurements with 300 mg L^{-1} amoxicillin were carried out using differential pulse voltammetry technique, in the range of -200 to 1000 mV with 25 mV amplitude at 50 mV s^{-1}. All experiments were carried out in an AUTOLAB micro potentiostat (Metrohm) PGSTAT 204.

2.4. Scanning Electron Microscopy (SEM) Imaging

The SEM imaging was performed in the JEOL equipment - Model JSM IT500HR. The image captures of the compounds were randomly selected in fields in the samples and at three magnifications: 10,000X, 20,000X and 30,000X. The preparation consisted in drying the solvent, from the samples suspended in aqueous medium, which were deposited on a glass slide and left in atmospheric air for 24 hours.

3. RESULTS AND DISCUSSION

3.1. Core-shell Characterization

Before applying the proposed sensor, it was necessary to characterize the core-shell to verify it was produced efficiently. Figure 2 shows the ultraviolet-visible (UV) spectra obtained for both the Fe_3O_4 nanoparticle (2A) and after its coating with silver nanoparticles to form the core-shell (2B), after dilution in deionized water (1:100).

Analysing Figure 2, it is possible to observe that for Fe_3O_4 nanoparticles there are two absorption bands, at 250 and 350 nm, which coincides with that obtained by Ramesh *et al.* (2017). For core-shell, it is verified that the absorption at 350 nm is maintained (referring to iron oxide) and there is the appearance of a band at 487 nm (highlight on Figure 2B) which refers to the resonance plasmons of silver, as described by Nana Kaka *et al.* (2023). Based on this analysis, it is possible to confirm the formation of the core-shell product Fe_3O_4@Ag.

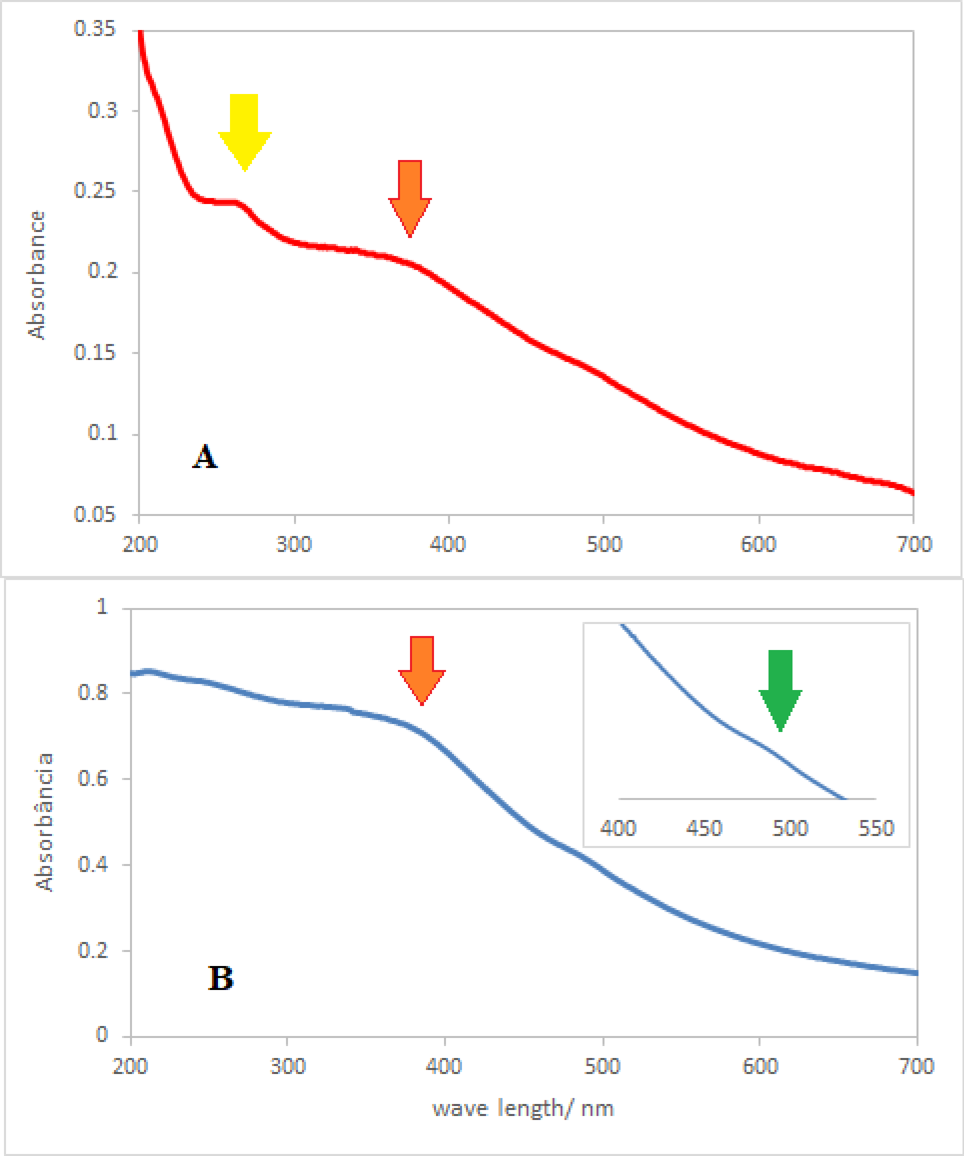

Figure 2. UV-Vis spectra obtained for Fe_3O_4 nanoparticles (A) and for the Fe_3O_4@Ag core-shell (B).

After spectroscopic characterization of the core-shell, images were obtained using scanning electron microscopy (SEM), aiming to estimate the morphology of the nanomaterial. The following were analyzed: (I) the pure Fe_3O_4 nanoparticles; (II) the Fe_3O_4@Ag core-shell and (III) the core-shell after coating with PVP. Figure 3 shows the results obtained, respectively.

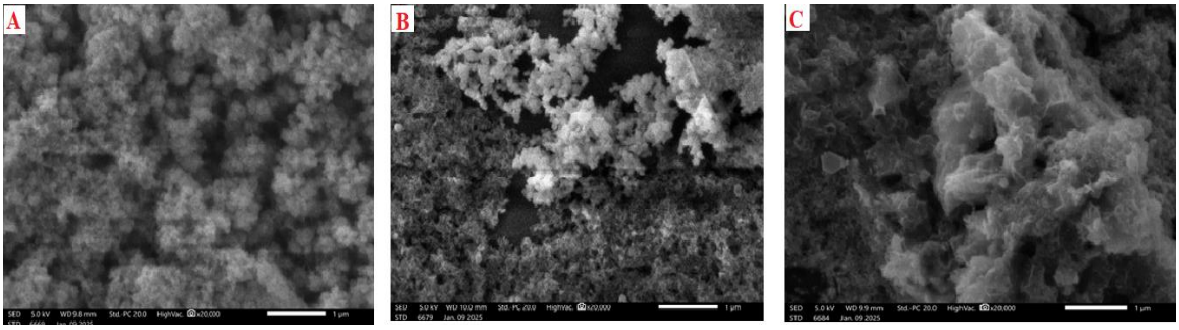

Figure 3. SEM images of the Fe_3O_4 nanoparticles (A); Fe_3O_4@Ag core–shell nanostructure (B) and Fe_3O_4@Ag/PVP nanocomposite (C) 20,000 times magnification.

Observing Figures 3, it is possible to verify different morphologies among the analyzed samples. It was not possible to perform measurements for the nanoparticle size, due to restrictions on the equipment and because of conditions of agglomeration and coating by other compounds.

In Figure 3A, aspects of nanoparticle clusters are observed throughout the sample field. These nanoparticles have spherical shapes and a high density of the nanomaterial is observed, showing the tendency to agglomeration. In Figure 3B, vacancies are noted in the sample field, indicating a tendency to deagglomeration in relation to the pure nanoparticles, which was already expected by the addition of silver. A certain increase in the nanostructures size was observed when comparing the images A and B. It also increased brightness in the images, establishing the silver coating. In Figure 3C, a film covering the material is noticeable which was not present in the previous images. The size of nanocomposite is larger than observed in the core-shell.

To verify the influence of the core-shell coating by PVP on the electrochemical measurements, measurements with 136 µmol L^{-1} amoxicillin solution were performed using differential pulse voltammetry (DPV) under the following conditions: (I) the pure Fe_3O_4 nanoparticles; (II) the Fe_3O_4@Ag core-shell; (III) the core-shell after coating with PVP and (IV) the core-shell after coating with PVP in 0.1 mol L^{-1} phosphate buffer solution. Figure 4 presents the results obtained.

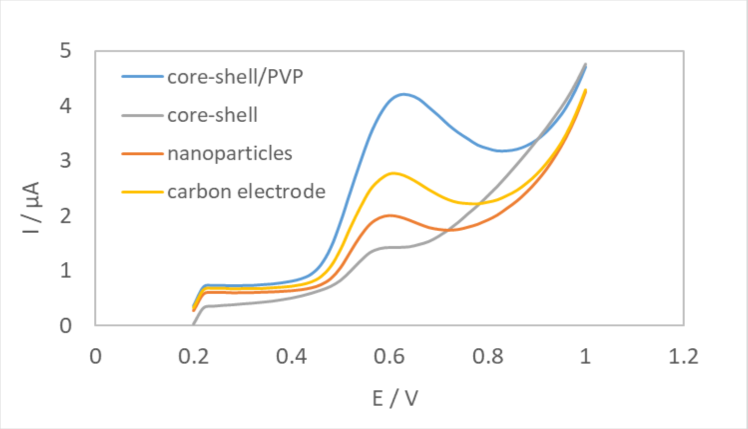

Figure 4. Differential Pulse Voltammograms of the Fe_3O_4 nanoparticles (A); Fe_3O_4@Ag core–shell nanostructure (B) Fe_3O_4@Ag/PVP nanocomposite (C) in 136 µmol L^{-1} amoxicillin solution in 0.1 mol L^{-1} phosphate buffer pH 7.0 and Fe_3O_4@Ag/PVP nanocomposite in 0.1 mol L^{-1} phosphate buffer pH 7. Pulse amplitude was 25 mV, at 50 mV s^{-1}.

A peak near 0.6 V shown in the voltammogram is due to the oxidation of hydroxyl (phenolic group) in carbonyl (ketone) in the amoxicillin molecule (Aihaiti *et al.*, 2021). Observing the voltammograms, it is possible to verify that the electrode modified with Fe_3O_4 nanoparticles provides a significant signal for the antibiotic since nanomaterials tend to improve electron transfer processes Prakash *et al.* (2013). When the core-shell was tested an increase in the signal was observed. This is because silver nanoparticles have catalytic properties, in addition to high electrical conductivity, which are advantageous in the development of electrochemical devices, contributing to an increase in the response (Huang *et al.*, 2014). With the addition of PVP, an increase in the electrochemical signal was observed because it prevents the nanoparticles agglomeration. Furthermore, it is highlighted that PVP covers the core-shell by hydrophobic bonds between polymer and the Ag nanoparticle (Garcia *et al.*, 2023). The response is not observed when the proposed sensor is evaluated in phosphate buffer solution

(4D). Table 1 presents the current values obtained.

Table 1. Current values obtained by DPV voltammograms for different configurations of devices in 136 µmol L^{-1} amoxicillin solution in 0.1 mol L^{-1} phosphate buffer pH 7.0.

Configuration	**I / µA**
Carbon printed electrode	1.4
Fe_3O_4 nanoparticle	2.0
Fe_3O_4@Ag	2.8
Fe_3O_4@Ag/PVP	4.2

Based on the data obtained by UV-Vis spectroscopy, SEM images and DPV measurements, we can confirm the satisfactory production of the core-shell as well as its subsequent coating by the polymer. Thus, the proposed architecture for the amoxicillin sensor proved to be very efficient and, therefore, the study of the optimization of the experimental conditions was followed.

3.2. Experimental Conditions Optimization

Before applying the proposed sensor to real samples, a crucial step is required to select the best experimental conditions. This allows us to increase the sensitivity of the device, since the conditions in which its response is maximum will be selected.

Firstly, studies were carried out involving the selection of the polymer to cover the core-shell: Polyvinylpyrrolidone (PVP), Diethanolamine and Chitosan. Then, differential pulse voltammograms were obtained in 820 µmol L^{-1} antibiotic solution in 0.1 mol L^{-1} phosphate buffer pH 7.0. Each polymer covers the core-shell for 30 min. The best response was obtained when PVP was used (data in Supplementary Material). Studies show that PVP helps maintain the colloidal shape of the nanomaterial, preventing it from undergoing aggregation processes, which could impair the signal (Pourmadadi *et al.*, 2023). Chitosan was the material that presented the lowest response, probably due to its terminal $-NH_2$ groups that did not contribute to the interaction with the analyte. Thus, PVP was used in subsequent experiments.

Another study is the most suitable PVP concentration for coating the Fe_3O_4@Ag core-shell. DPV measurements were carried out on the device containing three different concentrations of the polymer: 100; 500 and 1000 mg L^{-1}. It was concluded that the best concentration to be used is 100 mg L^{-1} (data in Supplementary Material) due to larger polymer concentration to lead to decrease in the response. This is probably because there is an increase in the thickness of the polymeric layer with larger concentration, which can hinder the transfer of electrons, leading to a decrease in the electrochemical signal (Wang *et al.*, 2023).

The latest study carried out refers to the interaction time between PVP and core-shell. The times evaluated were: 15, 30, 45 and 60 minutes. Analyzing the results obtained (data in Supplementary Material), increasing the interaction time increases the signal. Longer times were not tested as they would not be appropriate for sensor assembly, especially considering more quickly in the construction, since the proposal is that it should be easy to use, prepare and to be applied in field analyses. Therefore, 60 min was selected for subsequent studies.

3.3. Analytical Curve

After optimization, the analytical performance of the proposed sensor was obtained with different concentrations of amoxicillin. Measurements were performed using differential pulse voltammetry with an amplitude of 25 mV at a scan rate of 50 mV s^{-1}. The voltammograms (A) and linear response by a calibration curve (B) are presented in Figure 5.

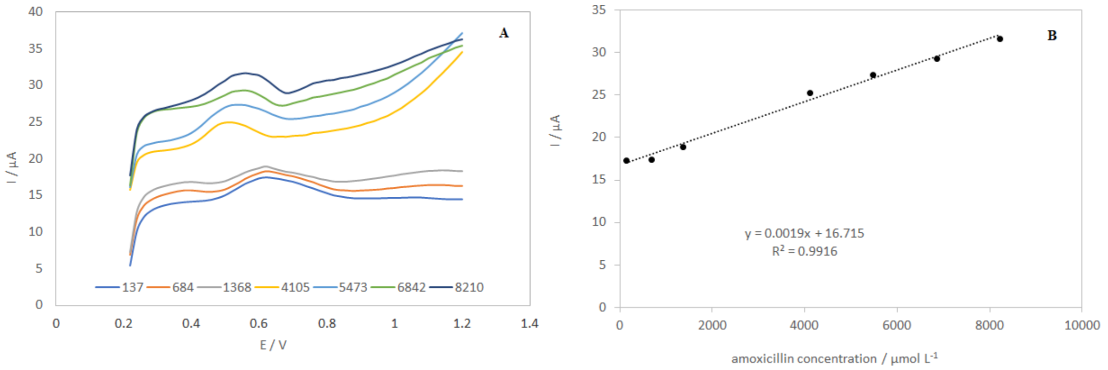

Figure 5. DPV (A) and calibration curve (B) of the proposed sensor at different concentrations of amoxicillin in 0.1 mol L^{-1} phosphate buffer, pH 7.0. The pulse amplitude was 25 mV, at 50 mV s^{-1}.

The analytical curve presents a linear range between 136 to 8210 µmol L^{-1} for amoxicillin with the straight-line equation $y(\mu A) = 0.0019\ x\ (\mu mol\ L^{-1}) + 16.715$ ($R^2 = 0.9916$, n=7). From the analytical curve, it was calculated the limit of detection (LOD) of 7.8 µmol L^{-1} and a limit of quantification (LOQ) of 26.5 µmol L^{-1}, using 3.3 Sd/b for LOD and 10 Sd/b for LOQ, being standard deviation of 10 blank measurements (Sd) and the angular coefficient of curve (b).

Analyzing Table 2 is possible to verify that the proposed sensor presents similar magnitudes of linear range when compared with other results in the literature. Furthermore, the proposed sensor is very simple to construct and has a low cost, since the material used as support is very easy to prepare and uses commonly found reagents.

Table 2. Proposed sensor characteristics.

Sensor	**Linear Range / mol L^{-1}**	**Limit of Detection / mol L^{-1}**	**Ref**
reduced graphene oxide molecular imprinted overoxidized polypyrrole modified with gold nanoparticles	10^{-8} to 10^{-3}	1.22 10^{-6}	Essousi *et al.* (2020)
glassy carbon electrode modified with reduced graphene oxide and Nafion	1.8–5.4 10^{-6}	0.36 10^{-6}	Valenga *et al.* (2020)
bismuth selenide nanoparticles modified reduced graphene oxide over molecular imprinted polymer	1.42–1100 10^{-6}	0.43 10^{-6}	Ali and El-Wekil (2023)
reduced graphite oxide nanosheet electrode	0.5–80 10^{-6}	0.193 10^{-6}	Pham *et al.* (2021)
ZnO semiconductor nanoparticles on graphite carbon sheets	10^{-4} to10^{-6}	0.121 10^{-6}	Zoubir *et al.* (2021)
Fe_3O_4@Ag/PVP on carbon printed electrode	136-8210 10^{-6}	7.8 10^{-6}	This work

3.4. Determination of Amoxicillin from Commercial Tablet

To verify the efficiency of the sensor in a real sample, it was tested in a commercial drug containing 500 mg of amoxicillin and 125 mg of potassium clavulanate. For the measurements, the tablet was macerated, 8 mg were diluted in a solution containing phosphate buffer pH 7.0 and methanol in a 10 mL flask. Considering the total mass of the tablet was 1.104 g, the expected amoxicillin concentration was 985 µmol L^{-1}. The measurements were performed in triplicate and the currents obtained were: 18.90; 18.32 and 18.24 µA. Substituting the average (18.49 µA) into the straight-line equation, the value found was 934 µmol L^{-1}. Thus, the relative error was 5.1%, considered excellent, since the medication contained clavulanate in its composition and excipients. It was verified that the other substances did not interfere significantly in the signal.

3.5. Determination of Amoxicillin in Natural Water

To verify the effectiveness of the sensor in a real sample, it was tested with a natural water sample from a lake located Campinas city, at Sao Paulo (Brazil). For the measurements, the natural water was fortified with 300 µmol L^{-1} of amoxicillin. The DPV measurements were performed using five measurements using different sensors constructed in the same conditions (one of the voltammograms in Supplementary Material). The maximum currents obtained were 17.41; 18.03 and 16.50 µA, whose average value was 17.30 µA. Substituting into the straight-line equation, 308 µmol L^{-1} is obtained. Thus, the relative error was 2.67%, considered excellent, since the lake water could contain other interfering substances. Thus, it is verified that the other substances did not interfere with the signal.

4. CONCLUSION

According to the results obtained in this work, it is possible conclude that the proposed sensor constructed by core-shell architecture of Fe_3O_4@Ag coated with polyvinylpyrrolidone (PVP) polymer, proved to be efficient for the detection and quantification of the antibiotic amoxicillin. The device presented satisfactory responses, with a low detection limit of 7.8 µmol L^{-1}, presenting a linear range between 136 and 8210 µmol L^{-1}. When applied to detect the presence of amoxicillin in natural water samples, it presented a low relative error of 2.7%, and in commercial drug samples, the error was 5.1%. Thus, it is proven that other substances present in the water or the tablet do not significantly interfere with the signal. In view of these facts, the miniaturized, low-cost, portable device can be used as a viable alternative for detecting antibiotics in real samples. These contaminants are not eliminated from water by traditional treatment methods, remaining in the matrix, even in low concentrations. The consumption of antibiotics is a concern due to bacterial resistance, which can cause harmful effects on society, including death, especially in urban areas.

5. ACKNOWLEDGMENTS

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Supplementary Data

1. Optimization of experimental conditions

Before applying the proposed sensor to real samples, a very important step is required to select the best experimental conditions. This allows us to increase the sensitivity of the device, since the conditions in which its response is maximum will be selected.

Firstly, studies were carried out involving the selection of the polymer to cover the core-shell: Polyvinylpyrrolidone (PVP), Diethanolamine and Chitosan. Then, differential pulse voltammograms were obtained in a 300 mg L^{-1} antibiotic solution in 0.1 mol L^{-1} phosphate buffer pH 7.0. Each polymer covered the core-shell for 30 min. Figure 1 presents the results.

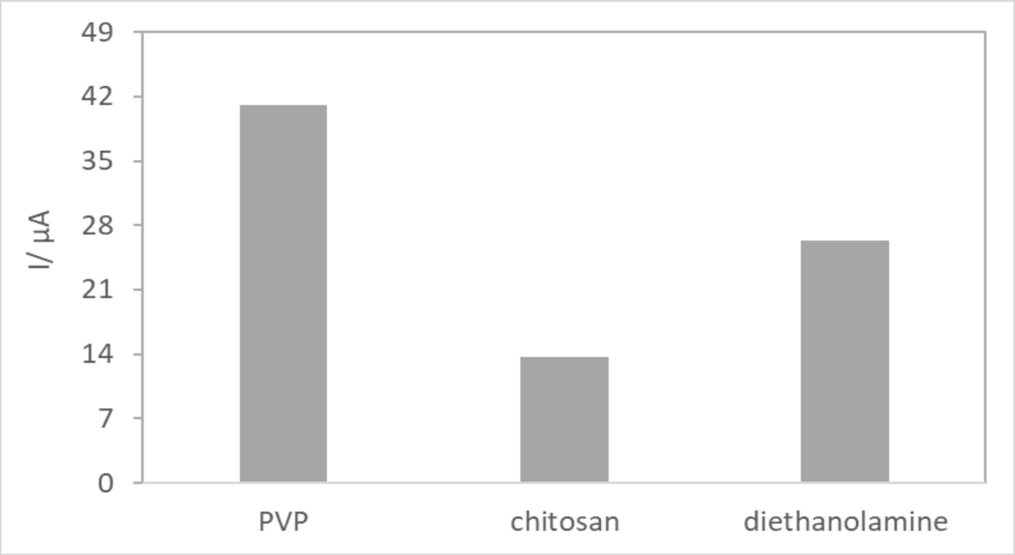

Figure 1. Currents obtained for carbon-printed electrodes containing Fe_3O_4@Ag core-shell coated with different compounds. In 300 mg L^{-1} amoxicillin solution in 0.1 mol L^{-1} phosphate buffer pH 7.0. Pulse amplitude was 25 mV, at 50 mV s^{-1}.

Observing Figure 1, it is possible to verify that the best response was obtained when PVP was used. Studies show that PVP helps maintain the colloidal shape of the nanomaterial, preventing it from undergoing aggregation processes, which could impair the signal (Pourmadadi et al., 2023). Chitosan was the material that presented the lowest response, probably due to its terminal $-NH_2$ groups that did not contribute to the interaction with the analyte. Thus, PVP was used in subsequent experiments.

Another study is the most suitable PVP concentration for coating the Fe_3O_4@Ag core-shell. DPV measurements were carried out on the device containing three different concentrations of the polymer: 100; 500 and 1000 mg L^{-1}. Figure 2 shows the results.

It was concluded that the best concentration to be used is 100 mg L^{-1} due to larger polymer concentration that leads to a decrease in the response. This is probably because there is an increase in the thickness of the polymeric layer with larger concentration, which can hinder the transfer of electrons, leading to a decrease in the electrochemical signal (Wang et al., 2023).

The latest study carried out refers to the interaction time between PVP and core-shell. The times evaluated were: 15, 30, 45 and 60 minutes. Analyzing the results (Figure 3), it can be seen that increasing the interaction time increases the signal. Longer times were not tested as they would not be appropriate for biosensor assembly, especially considering more quickly in the construction, since the proposal is that it should be easy to use, prepare and to be applied in field analyses. Therefore, the time of 60 min was selected for subsequent studies.

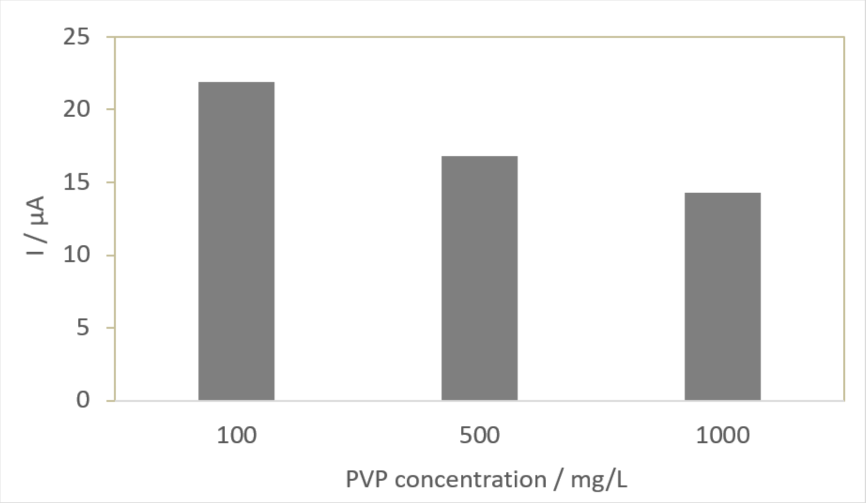

Figure 2. Currents obtained for carbon-printed electrodes containing Fe_3O_4@Ag with different concentrations of PVP. in 300 mg L^{-1} amoxicillin solution in 0.1 mol.L^{-1} phosphate buffer pH 7.0. Pulse amplitude was 25 mV, at 50 mV s^{-1}.

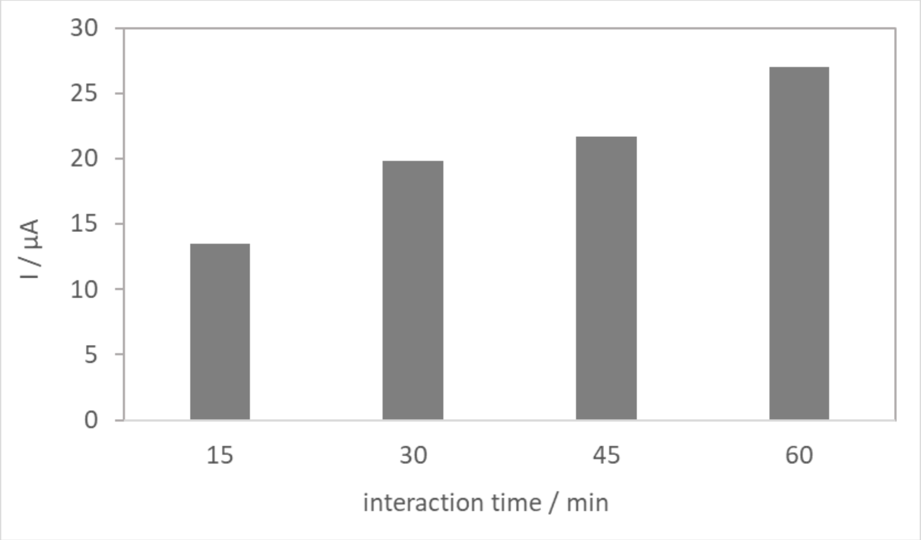

Figure 3. Currents obtained in different times of interaction between Fe_3O_4@Ag core-shell and PVP. in 300 mg L^{-1} amoxicillin solution in 0.1 mol L^{-1} phosphate buffer pH 7.0. Pulse amplitude was 25 mV, at 50 mV s^{-1}.

2. Determination of Amoxicillin from Commercial Tablet

To verify the efficiency of the sensor in a real sample, it was tested with a commercial drug containing 500 mg of amoxicillin and 125 mg of potassium clavulanate. For the measurements, the tablet was macerated, 8 mg were diluted in a solution containing phosphate buffer pH 7.0 and methanol in a 10 mL flask. Considering the total mass of the tablet was 1.104 g, the expected amoxicillin concentration was 985 µmol L^{-1}. The measurements were performed in triplicate and the currents obtained were: 18.90; 18.32 and 18.24 µA. Substituting the average (18.49 µA) into the straight-line equation, the value found was 934 µmol L^{-1}. Thus, the relative error was 5.1 %, considered excellent, since the medication contained clavulanate in its composition and excipients. It was verified that the other substances did not interfere significantly in the signal. Figure 4 presents the voltammogram obtained.

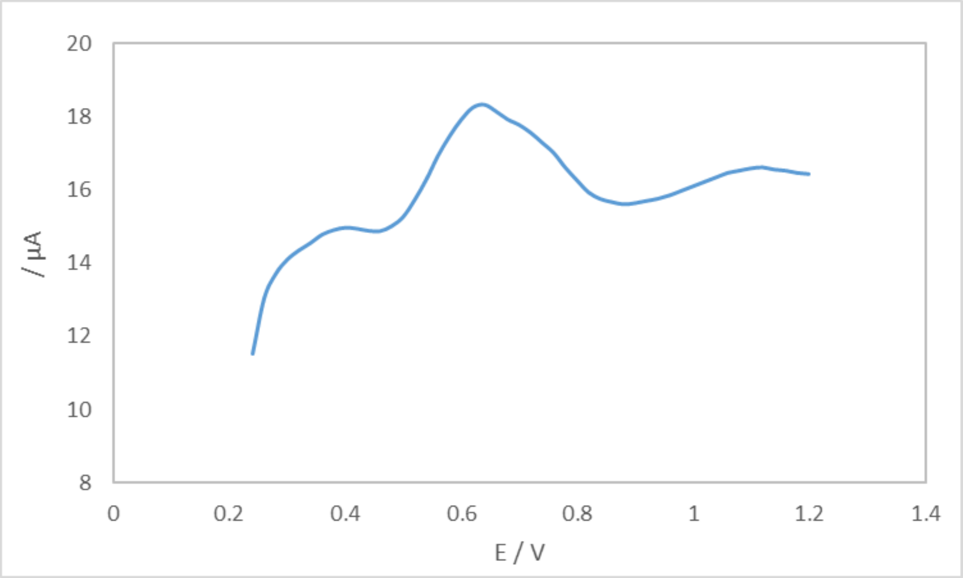

Figure 4. Differential Pulse Voltammogram of the sensor in commercial tablet solution in 0.1 mol L^{-1} phosphate buffer pH 7.0. Pulse amplitude was 25 mV, at 50 mV s^{-1}.

3. Determination of Amoxicillin in Natural Water

To verify the effectiveness of the sensor in a real sample, it was tested with a natural water sample from a lake located Campinas city, at Sao Paulo (Brazil). For the measurements, the natural water was fortified with 300 µmol L^{-1} of amoxicillin. The DPV measurements were performed using five measurements using different sensors constructed in the same conditions. The maximum currents obtained were 17.41; 18.03 and 16.50 µA, whose average value was 17.30 µA. Substituting into the straight-line equation, 308 µmol L^{-1} is obtained. Thus, the relative error was 2.67 %, considered excellent, since the lake water could contain other interfering substances. Thus, it is verified that the other substances did not interfere with the signal. Figure 5 presents the voltammogram obtained.

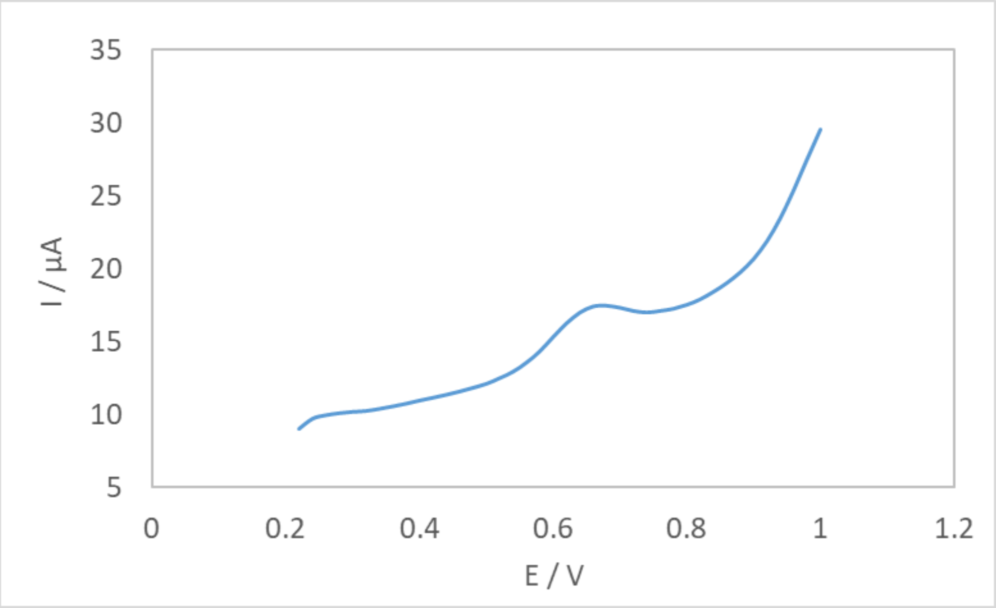

Figure 5. Differential Pulse Voltammogram of the sensor in natural water fortified with 300 µmol L^{-1} of amoxicillin. Pulse amplitude was 25 mV, at 50 mV s^{-1}.